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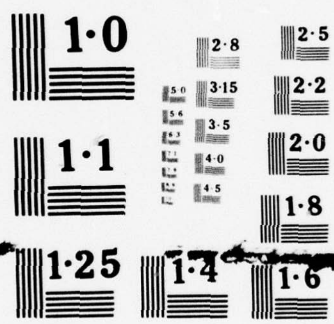

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METHOD FOR THE STUDY OF INFILTRATION UNDER FIELD CONDITIONS: FIRST RESULTS

A. Feodoroff

CORPS OF ENGINEERS, U.S. ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
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A METHOD FOR THE STUDY OF INFILTRATION UNDER FIELD CONDITIONS

FIRST RESULTS*

A. FEODOROFF

Soil Laboratory Section - VERSAILLES

Sci. Sol. No. 1, 1970

SUMMARY

The method consists of estimating the penetration of rainwater by the reaction of tensiometers located at different depths. It permits calculating the rates of infiltration and of drainage (or of redistribution) as well as the extent of saturation of the soil by the feedwater. At a second stage, these results can be related to the characteristics of the soil (porosity, initial moisture content, water deficit) and to the rainfall intensity.

INTRODUCTION

Erosion by stream action is generally brought about by the fact that a more or less large portion of the rain is not absorbed by the soil and can consequently run off when there is a slope. The problem is to establish the relation between the properties of the soil and the characteristics of the rain, which contribute jointly to prevent absorption.

There is every reason to believe that in soil of good structural stability (HENIN, 1969), this phenomenon appears when the water occupies all, or nearly all, of the porosity of the medium.

* Communication at the International Symposium on Erosion - Prague, June, 1970

Various laboratory studies (RUBIN, 1964; FEODOROFF, 1965) have shown that moisture infiltrating into initially dry soil depends on the materials studied and on the intensity of the rainfall. An estimate of this volumetric moisture content h is given by:

$$h = h_o + \frac{100\ I}{V} \qquad (1)$$

where

h_o is the initial moisture content in vol. %

I is the intensity of the rainfall LT^{-1}

V is the speed of the infiltration front LT^{-1}

This estimate would be rigorously accurate if one could determine the speed of the transmission zone and not that of the front.

Hypothetical Distribution of Water

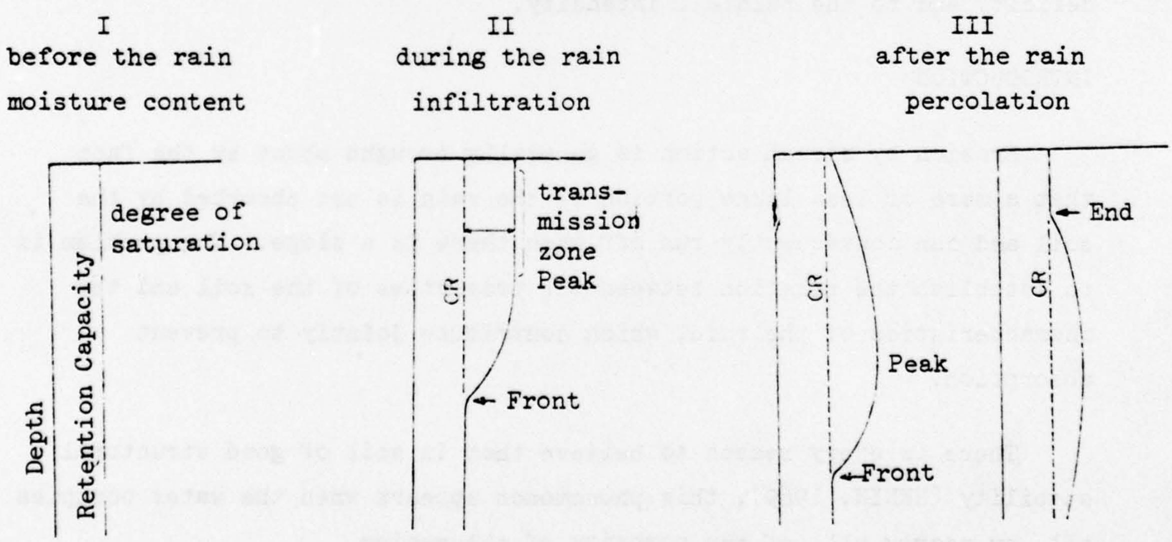

Figure 1. Development of Moisture Content and of Pressure During Infiltration (A. Feodoroff, 1969)

(continued on next page)

Expected Tensiometer Reaction

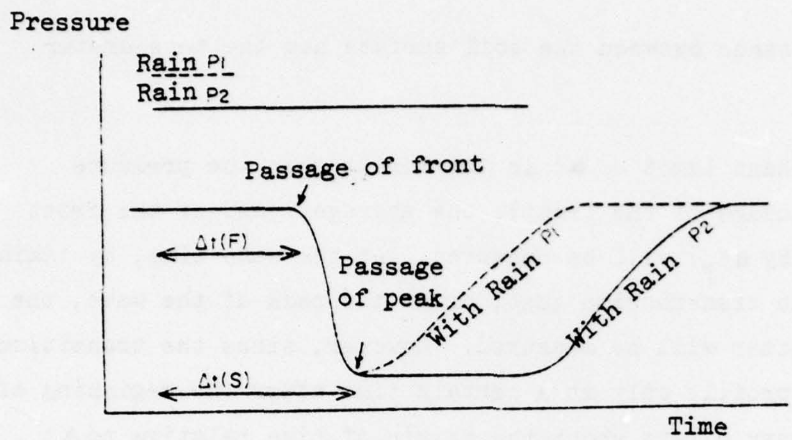

Figure 1 (cont.). Development of Moisture Content and of Pressure During Infiltration (A. Feodoroff, 1969)

*

Third, to the extent that the water content increases, the pressure falls. It reaches a minimum for a maximum of moisture content. Two cases can then occur:

(a) the rain continues. The water content remains at a constant value (transmission zone) and the pressure remains at its minimum value;

(b) the rain ceases (or had already ceased). One observes a degrease of the moisture content and therefore an increase of pressure until these measurements resume their initial value in the case of percolation, and a new stable value in the case of redistribution.

Knowing the time when the rain commenced, it is possible to measure the interval of time Δt separating the beginning of the rain and the reaction of the tensiometer. Thus is obtained an overall speed of penetration of water V:

* Translator's Note: Page 20 is missing from the French text.

$$V = \frac{L}{\Delta t}$$

where L is the distance between the soil surface and the tensiometer cup.

If the right-hand limit of Δt is the moment when the pressure begins to drop (passage of the front), the average speed of the front V_F (characterized by Δt_F) will be measured. At the same time, by taking Δt_S relative to the transmission zone, or at the peak of the wave, the speed V_S of the latter will be measured. However, since the transition zone is formed in profile only at a certain time after the beginning of the rain, uncertainty exists about the origin of time relative to Δt_S. In any case, the uncertainty disappears if the calculation is carried out for two tensiometers placed at different depths.

A speed of <u>infiltration</u> will be measured if the intervals Δt_F or Δt_S <u>are totally covered</u> by the period T_p of the rainfall ($T_p > \Delta t$). Otherwise, if $T_p < \Delta t$, (illustrated in the figure by Rain P), the time interval Δt encompasses a period of infiltration followed by a period of percolation or redistribution. In this case, the speed V is the resultant of the two consecutive phenomena.

The facts thus obtained can be used with Equations (1) and (2). Lacking a direct measurement of V_S, it is considered that during the rainfall, the curve is displaced by translation and thus that $V_S = V_F$. The calculation of the degree of saturation I/V will then be made with the values of V_F.

Under conditions of soil in the ground, an initial uniform moisture content can probably only be present for two specific values: the retention capacity or the fading point. In exposed soil, only the first case has an opportunity to arise in a temperate climate, and it is here that our observations apply. In any case, it is very frequently found that the soil may be partially dried out on the surface; we will also examine the process of infiltration and of consecutive redistribution

in this situation which does not correspond to the simpler scheme presented above.

Finally, it is apparent that in the field, one does not control the factors (moisture content of the soil, amount of rainfall), and it is necessary to accept them as they occur. The problem therefore consists of systematizing the measurements in order to collect the maximum amount of information. A series of observations have been carried out starting in 1963 at Versailles, on a silt soil kept without vegetation. The variables measured "in situ" are the rainfall, the moisture content of the soil, the pressure (absolute value of the negative pressure), and the piezometric level. The moisture content is measured weekly by removal of samples. The other variables were measured daily (first series of measurements), and are now being recorded.

II. FIRST SERIES OF MEASUREMENTS (1) (without recording)

The observations were made on a silt soil containing approximately 20% of clay, 22% of silt (2-20 microns), and 30 to 40% of very fine sand (20-50 microns). Porosity: 50.5 cc/100 cc.

In examining Figure II, it is observed that in the two layers studied and during the period under consideration, the water content remained relatively constant. Some "levels" of the same type were observed at other periods of the year, and the average water content of these levels has been compared with the retention capacity in the field (method of RODE, 1960). Its value is 28 cc/100 cc.

During this same period, the measured pressure fluctuated notably, sometimes indicating a slow recovery when the soil dried on the surface, or falling rapidly to very low values following significant rainfalls. This latter observation has been put to use to follow the process of infiltration according to the scheme previously described.

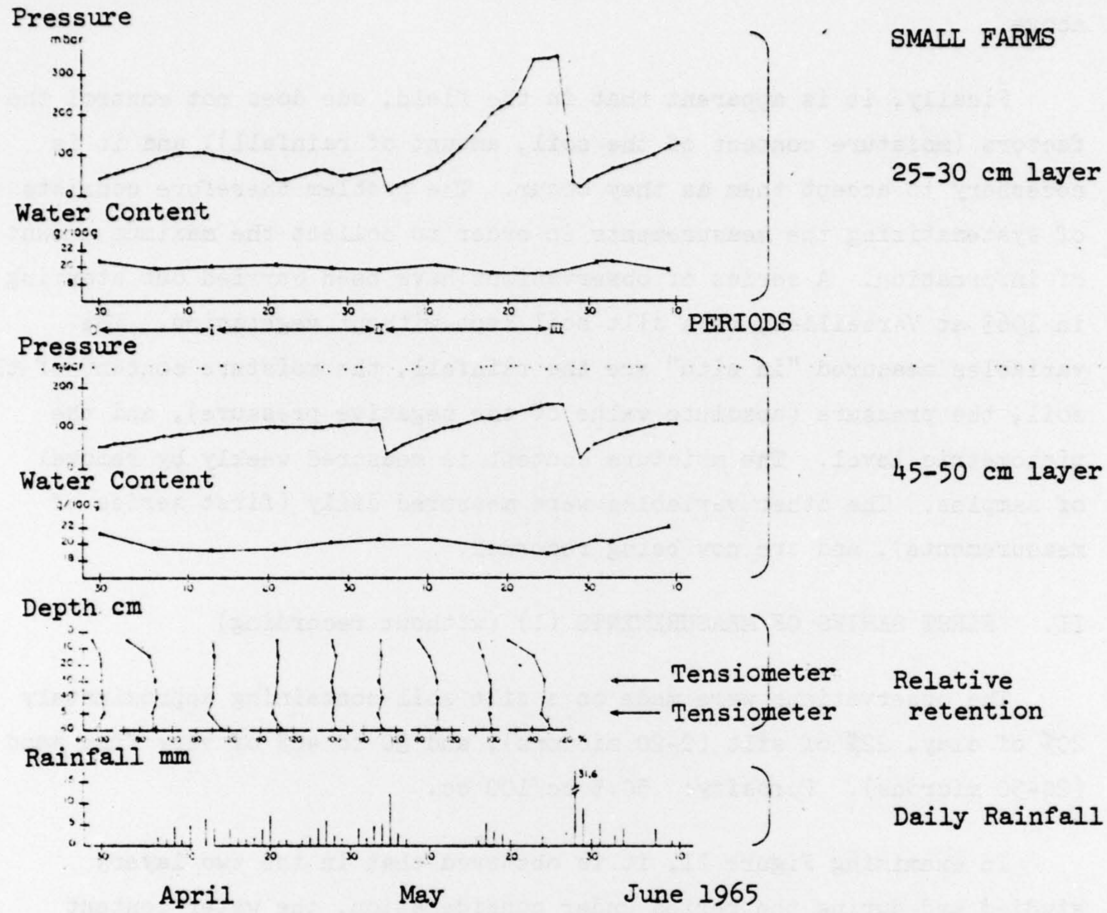

Figure II. Comparative Development of Water Content and of Pressure for Two Soil Layers. Field tests at Versailles. The relative retention is the water content in per cent of the retention capacity.

A. - DOWNPOUR OF SEPTEMBER 29, 1965 (Fig. III).

The rainfall of the 29th (24.9 mm) fell on soil whose moisture content corresponded essentially to the retention capacity. In fact, the measurement of the 28th indicated a water deficit (1) of 2.4 mm. The rain on this day (6.3 mm) therefore filled this deficit and created a slight excess detectable by a reaction of the deepest tensiometer. Starting

(1) Difference between retention capacity and measured moisture content.

with this situation, we shall analyze the infiltration of the rain of the 29th, using the tensiometer readings at a depth of 45 cm.

The pressure drop following this rainfall is probably linked to the passage of the water wave at the level under consideration. If one admits that the peak of the wave reached the figure -45 cm on the 30th of September at noon, one has an estimate of the time interval Δ t between the arrival of the rain at the surface of the soil and its penetration to 45 cm. Starting from here, it is possible to calculate a speed of penetration which amounts in the present case to 2.14 cm/hr. This value concerns essentially infiltration during the rainfall.

Drainage. - After the passage of the peak of the wave, the pressure climbs progressively with values essentially equal at the two levels, which shows that the process is essentially gravitational. Five days after the rainfall (October 5), the pressure value has reached about half of that existing before the rain (70 mbar vs. 140). The water content is in the neighborhood of the retention capacity, within the limits of error.

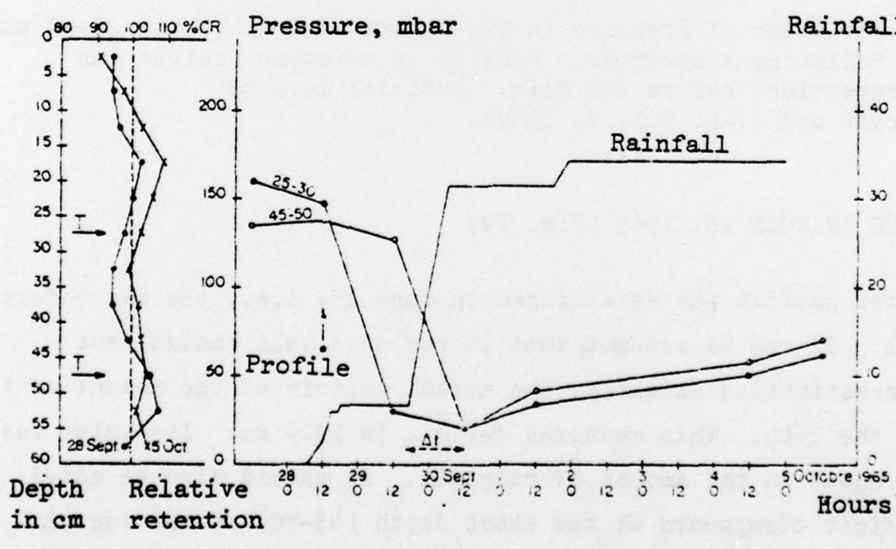

Figure III. Pressure Variation in Two Layers of Soil (Depth 25-30 and 45-50 cm) Following a Downpour. Profile of moisture content (as relative retention) before and after the rainfall. No deficit before the rainfall (A. Feodoroff and J.-L. Ballif, 1969).

Following this rain, the surface level of the water table rose 35 cm in four days, which probably corresponds to the percolation of all of the precipitation.

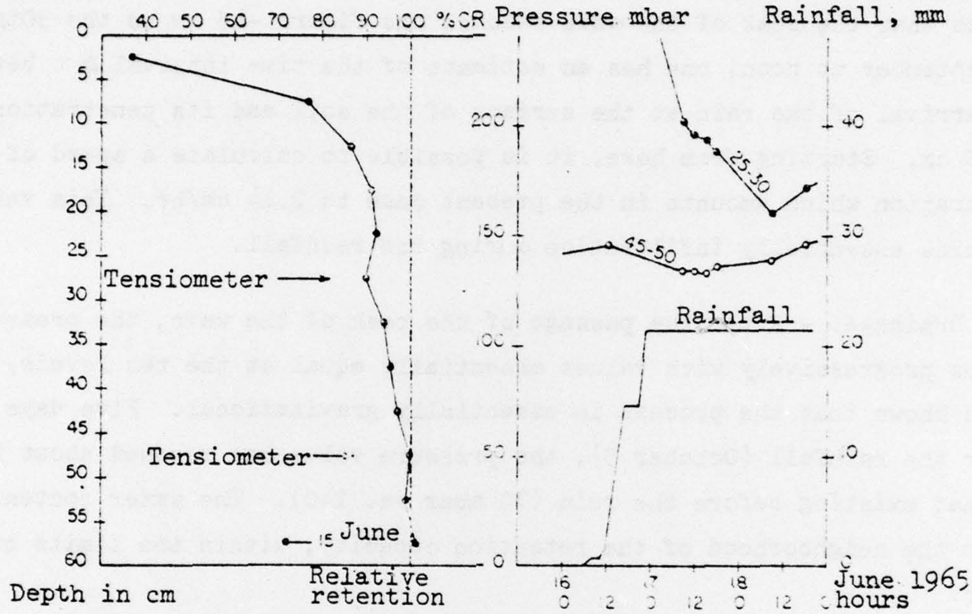

Figure IV. Variation of Pressure in Two Layers of Soil (Depth 25-30 and 45-50 cm) Following a Downpour. Profile of moisture content (as relative retention) before the rain. Deficit: 19.9 mm (A. Feodoroff and J.-L. Ballif, 1969).

B. - DOWNPOUR OF JUNE 16, 1965 (Fig. IV)

The water profile was established on June 15, i.e., the day before the rainfall. It can be assumed that it reflects well enough, but perhaps underestimating slightly, the actual deficit at the moment of the rainfall of the 16th. This measured deficit is 19.9 mm. Its value was practically equal to the amount of rainfall. It should also be noted that the deficit disappears at the exact depth (45-50) of the second tensiometer.

The pressure decreases in the surface equipment and passes from 320 mbar the day before to a minimum of 160 mbar: this relatively elevated value probably corresponds to the rehydration up to the retention capacity, without indicating an excess in comparison with this value.

The significant fact is that the second tensiometer (45-50) does not react in any significant manner, and nothing occurs to indicate that the rainwater has reached this depth.

The speed of penetration can be calculated for the 0-25 layer. The peak of the wave passes 45 hours after the beginning of the rain. The calculated speed is essentially related to the redistribution process. The value of 0.56 cm/hr. is found.

The studied rainfall does not reach the level of the water table, which continues to fall; the observation made with the tensiometers is thus confirmed.

These two examples show that with tensiometers, it is possible to reply quantitatively to a number of questions relative to the future of a rainfall in ground soil:

- the amount of rainfall corresponding to the water deficit in comparison with the retention capacity is removed by the dried layers, and thus escapes percolation toward the water table;

- in the absence of a deficit, all of the rainfall is found at the water table surface. The percolation of water in excess of the retention capacity takes place by gravity, as indicated by the laboratory experiments (A. FEODOROFF, 1969);

- the speeds of infiltration, redistribution, and percolation can be calculated from the tensiometer measurements;

- knowing the intensity I of the rainfall and the speed V of the infiltration, one can also calculate the degree of saturation of the soil by the feed water, given by I/V. In a situation favorable to this

calculation (sufficiently extended rainfall to include definitely all of the pressure drop), we have found a saturation level of 8.3 vol.-%. In this soil, the total porosity is 50.5 vol.-% and the retention capacity is 28%. It can thus be seen that the rainwater in motion occupies only a small part of the macroporosity (8.4% vs. 22.4%), which perhaps reinforces the observations of GUYON (1965) and of SINE and GASPAR (1965) on the porosity liberated by the lowering of the water table.

III. SECOND SERIES OF MEASUREMENTS (with recording).

In the cited study, a certain imprecision is associated with the determination of Δt, and thus of the speed and the derived values. This results from the fact that the pressure measurements were carried out "on demand". To alleviate this disadvantage and consequently to refine the quantitative usefulness of the results, we have been led to record the pressure as well as the rainfall and the piezometric level.

TABLE. Infiltration in the 0-25 cm Layer (Farm C)

Date	RAINFALL			Water deficit of the soil before the rain	INFILTRATION		
	Amount mm	Duration Hours	Intensity I mm/h		Speed V mm/h	Degree of Saturation 100/V cc/100 c	
15/9/67	11,0	7,3	1,51	oui	31,0	-	
4/10/67	10,0	4,0	2,50	oui	83,3	-	
20/6/68	6,3	2,5	2,54	oui	83,3	-	
6/7/68	16,4	8,0	2,05	oui	66,5	3,1	
2/9/68	17,4	19,0	0,92	oui	62,5	1,5	Water
3/9/68	12,6	16,75	0,75	non	55,5	1,4 ←	deficit
4/9/68	10,2	12,0	0,85	non	66,5	1,3	effect
16/9/68	15,7	20,0	0,78	oui	25,0	3,1	
24/9/68	9,2	15,5	0,61	non	41,7	1,5 ←	Intensity
29/9/68	14,0	14,0	1,00	ε	43,5	2,3	effect
10/10/68	8,8	7,0	1,26	non	62,5	2,0	

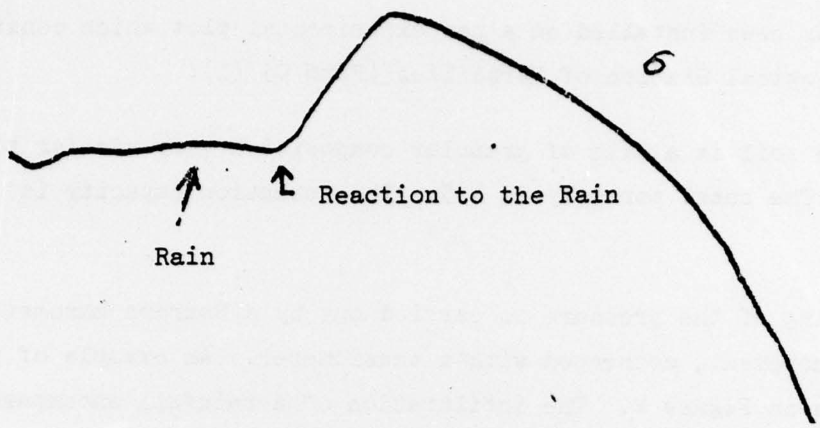

Figure V. Variation of the Pressure (Recorded). Pressure drop following a rainfall (A Feodoroff, 1969).

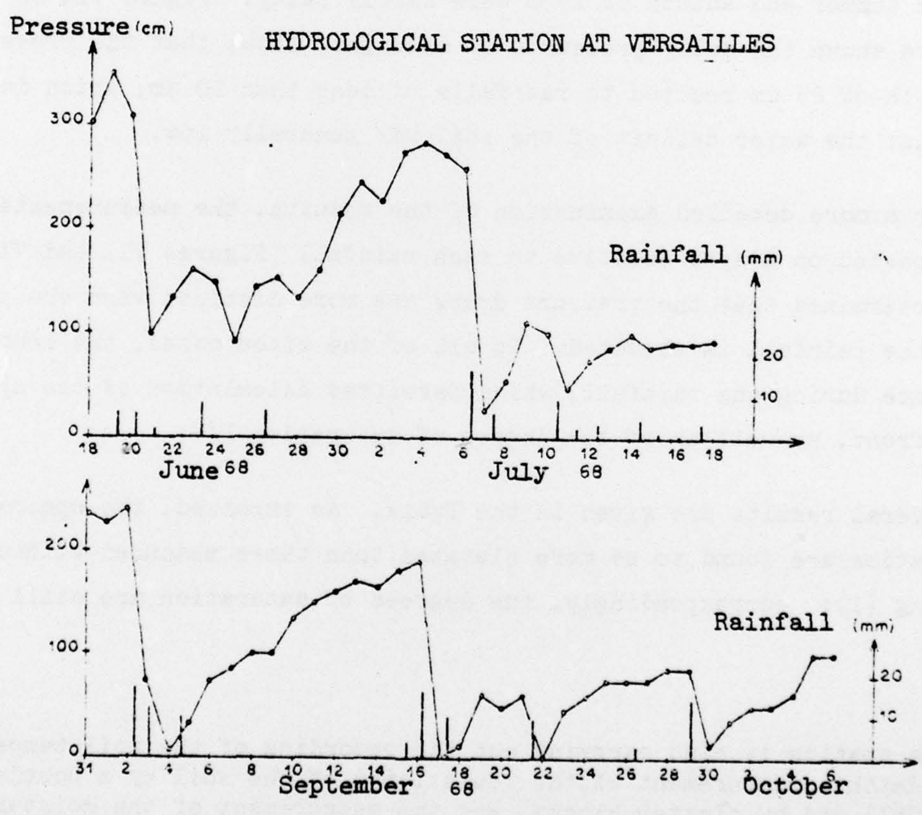

Figure VI. Development of Pressure (at Midnight) at a Depth of 25 cm in an Exposed Silt Soil.

Such a device has been installed on a new experimental plot which constitutes the Hydrological Station of Versailles (Farm C) (1).

The surface soil is a silt of granular composition very similar to the preceding. The total porosity is 45%. The retention capacity is 32 cc/100 cc.

The recording of the pressure is carried out by a Bourdon manometer, with clockwork movement, connected with a tensiometer. An example of the diagram is given in Figure V. The infiltration of a rainfall encompasses a rapid pressure drop whose residual effects persist in the following days. The passage of the infiltration "front" can thus be observed (beginning of the pressure drop) and its speed can be calculated.

The summer and autumn of 1968 were fairly rainy. Figure VI, on which are shown the daily pressures at midnight, shows that the pressure at a depth of 25 cm reacted to rainfalls of less than 20 mm, which indicates that the water deficit of the soil was generally low.

For a more detailed examination of the results, the measurements have been reported on graphs relative to each rainfall (Figures VII and VIII). It is determined that the pressure drops are more distinct when the pressure before the rainfall is elevated. In all of the cited cases, the reaction took place during the rainfall, which permitted calculation of the speed of the front, as well as of the degree of saturation I/V.

Several results are given in the Table. As expected, the speeds of infiltration are found to be more elevated than those measured without recording (1); correspondingly, the degrees of saturation are still lower.

(1) This station is also carrying out the recording of the soil temperature at six depths, measurement of the resistivity of the soil by a Dobrjansky bore (1967) and by plaster blocks, and the measurement of the moisture content by removal of samples.

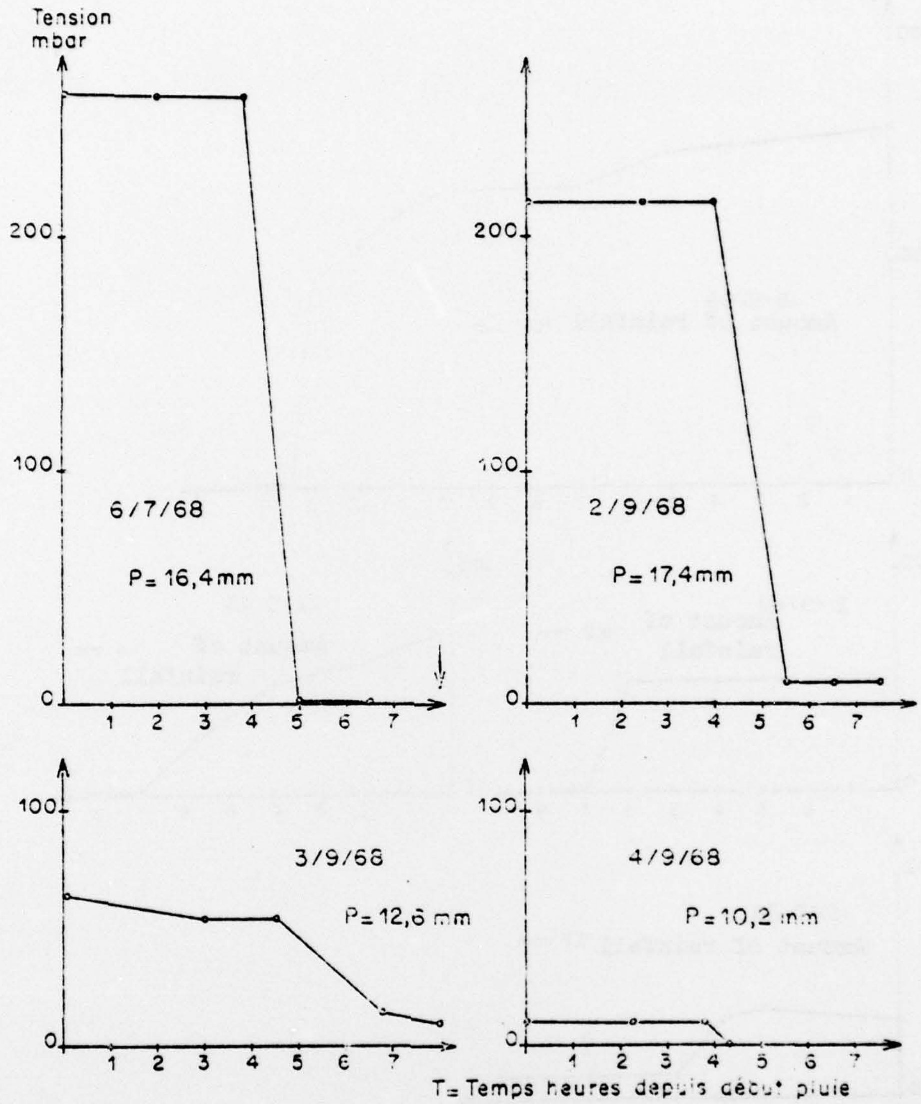

Figure VII. Pressure Development on the scale of a downpour. The abscissa is the time in hours since the beginning of the rainfall. The arrow possibly indicates the end of the precipitation. The minimum values of the pressure cannot be shown in Figure VI, where only a single point per day is shown.

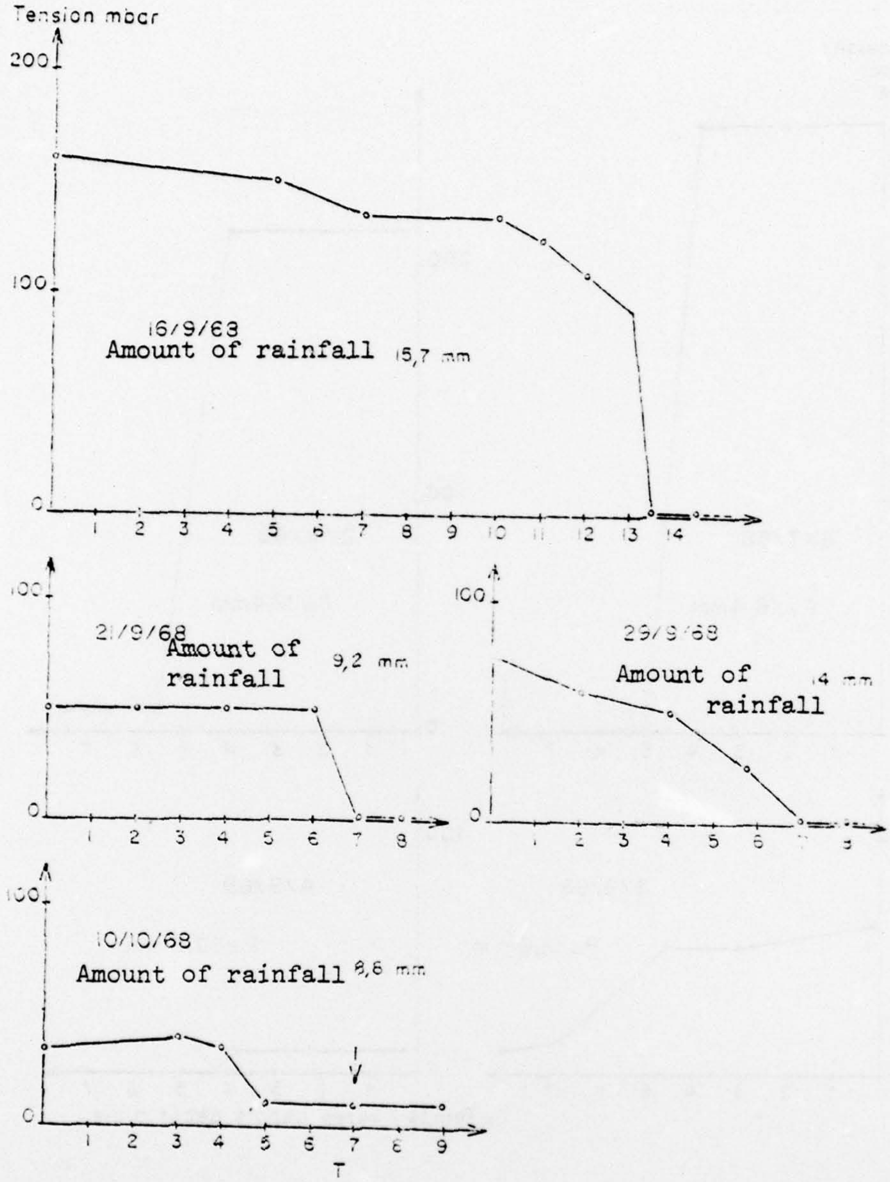

Figure VIII. Development of Pressure on the Scale of a Downpour. The abscissa is the time in hours since the beginning of the rainfall. The arrow possibly indicates the end of the precipitation. The minimal values of the pressure may not appear in Figure VI where only a single point is given for each day.

Furthermore, it is possible to note at least qualitatively the influence of certain factors on infiltration in the non-saturated condition. Everything else being approximately the same, there is observed a positive intensity effect. In fact, its increase (from 0.61 to 1.26 mm/hr.) leads to an increase (less than proportional) of the infiltration speed. These results are in line with Equation II. Correspondingly, the degree of saturation increases with the intensity. In any case, it is to be noted that for the soil under consideration, the greatest saturation in the course of infiltration (32 + 2.0 = 34.0 cc/100 cc) is still far from reaching total saturation (45 cc/100 cc).

When the soil is partially dried out before the rainfall, the speed of infiltration is reduced. Furthermore, the degree of saturation is then increased. These two observations are probably the result of withdrawal of the water by the soil up to the point of replenishment of the deficit.

CONCLUSIONS

A better understanding of infiltration in the natural medium has necessitated the utilization of a study device with recording of different variables, including water pressure in the soil. We have thus been able to follow the penetration of a series of rainfalls into a soil under various conditions of moisture content.

Information collected by this group of studies leads us to the conviction that, in the non-saturated region, there exist two systems of runoff depending on whether the initial moisture content is lower than or equal to the retention capacity. In the first case, the feed water tends to occupy the fraction of porosity left free by the water deficit; the water is thus stored slowly and does not run off to the water table, although it can certainly participate in nourishing plants. We therefore again find a negative effect of the water deficit on the speed of infiltration, already noted by CANARACHE (1966) from experiments on infiltration under pressure.

When the water deficit is filled, an essentially gravitational runoff is observed, which feeds the water table. The speed of infiltration and the degree of saturation of the soil are thus determined by the intensity of the rainfall, which conforms with expectations. The described method should thus be able to permit studies in the field of the modes of infiltration in soils submitted to various rainfall regimens, and notably to downpours capable of causing lack of absorption.

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(1) Speed of infiltration in a saturated medium measured by the method of Vergieres is 50 to 60 mm/hr. (NORMAND, BOURRIER, Comm. verb.).